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MAGNANIMITY OF THERMAL POWER PRODUCTION ENGINEERING TECHNOLOGICAL BREAKTHROUGHS: AN EMPIRICAL ANALYSIS OF ADAPTATION TO CLIMATE CHANGE IN INDIA

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ABSTRACT

In consideration of the practical fact, in terms of our long term needs and effects of thermal electric energy production, the Electric Energy-Water- Climate seasonal link makes it essential for adaptation to climate change and its effective management in a sustainable manner for future. In this research paper, the author uses a long panel data set of few selected Indian thermal power plants that are thermal based for the time period 2000-2001 to 2008-2009 to test certain hypotheses regarding thermal power plant performance with respect to water withdrawals vis-a-vis power generation relative to normal seasonal variation using Advanced Statistical Technique specifically can be mentioned as "Seasonal Variation Index". The study finds strong, robust evidence in support of water shortage owing to the impact of changing climate. Cooling towers as technological breakthrough are preferred due to erratic seasonal monsoons in summer season. This paper evaluates the performance and effectiveness of cooling tower mechanism as per Bureau of Energy Efficiency technical parameters in the present arena of 21st century Global Environmental Sustainability. The assessment of cooling towers in selected power stations clearly indicates that, the technology was able to counteract the water shortage problem in the respective power stations to a certain extent. Keeping in view of resource inefficiency i.e. in terms of water utilization, this paper suggests pertinent sustainable developmental management strategies and spatial technologies as a policy recommendation to abridge the water gap in arid regions of selected thermal power plants.

KEYWORDS: Seasonal Variation, Cooling Tower, Evaporation Losses & Heat Load

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Original Article

INTRODUCTION

The recent Intergovernmental panel on climate change reports the fact that climate change will hit through the water and many regions of the World will experience increased water shortages. The etymological justification for water scarcity can be substantiated with authenticated empirical research that supports the academic viewpoint that the per capita availability of fresh water has declined sharply from 3,000 cubic meters to 1,123 cubic meters over the past 50 years. The global average is 6,000 cubic meters. The World Bank Study about Climate Change, Water and Economy reveals startling facts that due to water scarcity and mismanagement of water, there will be deceleration of 6 % GDP in terms of Economic Growth by 2050 in India. If the country efficiently manages water in a sustainable manner it can add 1% to its GDP. The hypothesis of the research paper constitute:

- The amount of electricity generated by fuel type thermal (non-renewable) depends on availability of fresh water in a 12 month period.

- The water availability due to varied climate change (seasonal fluctuations) affects electric energy production and its effectiveness in terms of Plant Load Factor. The paper emphasizes on research objectives such as to highlight the bottleneck of water shortage and evaluate the performance of the cooling tower mechanism in power stations with a Sampling Design of three regions of Andhra Pradesh viz; Coastal Andhra Pradesh, Rayalaseema and Telangana are selected. In each of these regions one power plant by fuel type of non-renewable energy source will be selected. They can be listed as follows:

Table 1: Selected Power Plant in Three Regions of Andhra Pradesh

Power Plant by Fuel Type	Coastal Region	Rayalaseema Region	Telangana Region
Thermal	Narla Tata Rao Thermal Power Station	Rayalaseema Thermal Power Plant	Kothagudaem Thermal Power Station

The respective cooling towers of Narla Tata Rao Thermal Power station in Coastal region are of Induced Draft counter flow with a fill. Whereas Kothagudem Thermal power station in Telangana region and Rayalaseema Thermal Power station in Rayalaseema region are considered, the cooling towers are of a Natural Drafts type. In Narla Tata Rao Thermal Power station induced draft cooling towers were in existence, with the facility of the open recirculating type of cooling system in NTTPs. Big power plants like NTTPs use this system, where there is limitation of water especially during lean seasons. This in turn depends upon the performance of cooling towers. The advantage of this system, is differential temperature can be achieved higher in comparison with once through the system of cooling. Therefore the minimum quantity of water is required for cooling.

METHODS OF EMPIRICAL FRAMEWORK: VULNERABILITIES OF WATER SHORTAGES TO ELECTRICITY GENERATION

Seasonal Variations occur within a period of one year or less. It is a component of time series, which is defined as repetitive and predictable (seasonal changes) around the trend line in one year or less. It is detected by measuring the quantity of interest for small intervals that is days, weeks, months and quarters. By this strong seasonal movements can be predicted. But when data are expressed annually there is no seasonal variation. A measure of seasonal variation is referred as Seasonal indexes (percent). They are given as percentages of their average. Electricity Supply Industry - Exhibits inquisitiveness in knowing their performance with respect to water withdrawals vis-à-vis power generation relative to normal seasonal variation with the aid of SVI i.e. it expects an increase or decrease in the growth of power generation (for both to prospective and lean period of a year)

Computation of Seasonal Variation Index in Thermal Power Plants

The following are the steps involved in the computation of Seasonal variation Index with respect to water withdrawals and loss of generation due to water shortage trends for various power plants by fuel type (Thermal). As an example the Seasonal Variation Index has been estimated for Kothagudaem O & M Thermal Power Station. (See table 2). The following procedural steps have been devised

Table 2: Kothagudaem O &M Thermal Power Station: Scenario of Water Withdrawals

Year		Water with Drawals (Hundred Million Cubic Meters)	X-code	4-q-m-a	Centred	Specific Seasonal	Deseasonalised
2003-04	1 Summer	2.09	1				1.9
	2 Rainy	2.32	2				1.92
	3 Winter	1.58	3	1.8	1.8	0.88	1.61
	4 Post Monsoon	1.21	4	1.7	1.7	0.71	1.29
2004-05	1	1.77	5	1.7	1.7	1.04	1.67
	2	2.08	6	1.8	1.8	1.16	1.71
	3	1.97	7	1.9	1.9	1.04	2.01
	4	1.92	8	1.9	1.8	1.07	2.04
2005-06	1	1.67	9	1.8	1.7	0.98	1.6
	2	1.50	10	1.7	1.6	0.94	1.2
	3	1.53	11	1.6	1.6	0.96	1.6
	4	1.70	12	1.7	1.7	1	1.8
2006-07	1	2.04	13	1.8	1.8	1.13	1.94
	2	1.76	14	1.8	1.8	0.98	1.46
	3	1.84	15	1.8	1.8	1.02	1.88
	4	1.62	16	1.8	1.8	0.96	1.72
2007-08	1	1.90	17	1.8	1.8	1.05	1.81
	2	1.82	18	1.8	1.8	1.01	1.5
	3	1.77	19	1.8	1.8	0.98	1.81
	4	1.66	20	1.7	1.7	0.98	1.76
2008-09	1	1.68	21	1.7	1.7	0.99	1.6
	2	1.58	22	1.7	1.6	0.99	1.3
	3	1.69	23	1.6			1.72
	4	1.56	24				1.66

Step 1: List the data in chronological order

Step 2: Determine the time period to be used for moving average (Here the data used are for quarterly purpose)

Step 3: Compute four quarter moving average. The first value in the third column is 1.8 = (2.09 + 2.32+ 1.58 +1.21) /4. The second value is calculated by moving down one quarter. (2.32 +1.58 +1.21+1.77) /4 = 1.7. By moving down 1 quarter at a time, we can calculate the rest of moving averages.

Step 4: Compute the centered moving averages by getting the average of two 4 quarter moving averages. EG. 1.8 + 1.7/2 = 1.8

Step 5: For obtaining specific, seasonal, compute the ratio by dividing actual water withdrawals (WD) by centering moving averages. For Eg: WD value 3 quarter (winter) 1.58/3 = 0.88 and so on and so forth.

Step 6: Later a seasonal index table is constructed by making use of the specific seasonal column. The purpose is to group together all first, second, third and fourth quarters to calculate a typical index per quarter.

Step 7: Total all the years for 4 quarters (i.e. summer, rainy, winter and post monsoon seasons) and divide by the number of observations to obtain unadjusted seasonal mean. The unadjusted seasonal means obtained are 1.04, 1.02 and 0.97 and 0.93 the total comes to 4.66.

Step 8: Determine the correction factor to adjust the unadjusted seasonal mean to adjusted seasonal means. For typical quarterly index = 100 ×4 = 400. Add all the unadjusted seasonal means. Correction Factor = 4/3.97 = 1.01

Multiply 0.9802 (CF) with an unadjusted seasonal mean. Then we obtain adjusted seasonal.

Step 9: Then ultimately multiply by 100, to obtain a typical seasonal index as 105, 121, 98 and 94.1.

Step 10: As per Indian monsoon conditions, the final seasonal index values are calculated for both water withdrawals and loss of generation. For the purpose of Four Quarterly moving averages, the SVI analysis has been done by bifurcating the Indian seasons as 3 months in each quarter. But in reality, the Indian monsoon period can be customarily categorized as follows: Rainy, winter, Medium Wet and Summer Season.

Table 3: Calculation of Seasonal Index

Year	Summer (Dry Season)	Rainy (wet Season)	Winter (Cold Season)	Post Monsoon
2003-04			0.88	0.71
2004-05	1.04	1.16	1.04	1.07
2005-06	0.98	0.94	0.96	1
2006-07	1.13	0.98	1.02	0.9
2007-08	1.05	1.01	0.98	0.98
2008-09	0.99	0.99		
Total	5.19	5.08	4.88	4.66
Unadjusted Seasonal Mean	1.04	1.02	0.97	0.93
Adjusted Seasonal	1.05	1.21	0.98	0.941
Seasonal Index	105	121	98	94.1

As per the Indian monsoon conditions, the Seasonal index values calculated are as follows:

Table 4

Final SVI	105 +32.67 =137.67	121+31.37 =152.37	98-32.67 =65.33	94.1-31.37 =62.73

Correction factor = 4/3.97 = 1.01

Trend equation: y = 1.97 - 0.09 x

Performance Evaluation of Cooling Towers

(As per the Bureau of Energy Efficiency [1] there are eight important parameters from the point of assessing the performance of cooling towers. They can be elaborated as follows)

- **Range:** It is the difference between the cooling tower water inlet and outlet temperature.
- **Approach:** It is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. Of these two, approach is considered as the best indicator of cooling tower performance.
- **Cooling Tower Effectiveness (in percentage):** is the ratio of range, to the ideal range. That is the difference between cooling water inlet temperature and ambient wet bulb temperature.

[1] It is an agency of the Government of India, under the Ministry of power created in March 2002 under the provisions of the nation's 2001 Energy Conservation Act. The agency's function is to develop programs which will increase the conservation and efficient use of energy in India

- **Cooling Capacity:** It is defined as the heat rejected in Kcal/hr, given as the product of mass flow rate of water, specific heat and temperature difference.

  Evaporation loss is the water quantity evaporated for cooling duty and theoretically for every 10, 00,000 Kcal heat rejected, evaporation quantity by default is taken as 1.8 m^3. Empirically, it can be represented as: -

$$m^3/hr, \text{Evaporation loss} = \frac{\text{Circulation rate}(m^3/hr)^* \text{ Temperature in } {}^{\circ}C}{675}$$

- **Cycles of Concentration:** It is defined as the ratio of dissolved solids in circulating water of the dissolved solids in makeup water. Blow down losses are other important for determining the performance of cooling towers. It depends upon cycles of concentration and evaporation losses and is represented as

$$\text{Blow down} = \frac{\text{Evaporation loss}}{\text{COC} - 1}$$

- **Liquid/Gas Ratio of a Cooling Tower:** It is defined as the ratio between water and the air mass flow rates. Against design values, seasonal variation in water availability requires adjustment and tuning of water and air flow rates in order to get the best of cooling tower effectiveness. Thermodynamics also indicate that the heat removed from the water must be equal to the heat absorbed by the surrounding air: L (T_1-T_2) = G (h_2-h_1)

$$\frac{L}{G} = \frac{h_2 - h_1}{T_1 - T_2}$$

Where, L/G = Liquid to gas mass flow ratio (Kg/Kg), T_1 = Hot water Temperature $^{\circ}$C, T_2 = Cold water Temperature $^{\circ}$C, h_2 = enthalpy of air-water vapor mixture at an exhaust wet bulb temperature, h_1 = enthalpy of air-water vapor mixture at an inlet wet bulb temperature

- **Heat Load:** The heat load put on cooling tower is assessed by the process being served. The degree of cooling required is monitored by the desired operating temperature level of the process. In many cases, lower operating temperature is desirable to increase process efficiency to enhance the quantity and quality of production. Wet Bulb Temperature: It is another main factor responsible for monitoring the performance of evaporative water cooling equipment.

EMPIRICAL RESULTS

Case Study 1: Kothagudaem Thermal Power Plant O&M

Installed Capacity: KTPS A 4 × 60 MW, KTPS B 2 × 120 MW, KTPS C 2 × 120 MW. 4 × 60+2 × 120 +2 × 120 = 720. At each station A, B and C comprise of different capacities, 720 Installed Capacity of Generation was taken as the standard for the calculation of Loss of Generation.

During 2008-09: April month Actual Generation= 370.56 MU, Loss of Generation (LG) due to poor quality of coal, outage on auxiliaries, auxiliary consumption and forced outage = 39.05 + 23.24 + 31.33 + 55.80 = 149.42 MU, Actual Generation –LG due to other factors = 370.56 - 149.42 = 221.14 MU, Installed Generation capacity - Loss of Generation due to miscellaneous factors =720 - 221.14 =498 MU and Therefore LG due to water shortage = 498 MU

May month Actual Generation: 380.921 MU, LG due to other factors = 33.17 + 21.05 + 40.26 + 33.54 + 12.54 = 140.56 MU, Actual Generation-LG due to other factors = 380.921-40.56 =240.361 MU. Therefore LG due to water shortage = 720-240.361 = 479.639 MU.

March month actual generation: 418.921, Loss of Generation due to other factors = 49.29 + 10.82 + 49.26 + 36.66 + 14.3 =153.42 MU, Actual generation –Loss of Generation due to other factors = 418.921 - 153.42 = 265.501 MU. Therefore LG due to water shortage = 720 - 265.501 =454.49. Therefore, ultimately the LG due to water shortage during summer season =498 + 479.64 + 454.499 =1432.1 MU or 14.32 hundred million units. The calculated figures of LG during rainy, winter and the post monsoon season are 21.86, 14.71 and 11.53 hundred million units. In a similar manner for all the quarters (4 seasons), LG due to WS during (2003-04 to 2008-09) has been calculated and SVI has been applied

For a period of seven years, **2003-04 to 2008-09:** (table 3), the four quarter wise results after application of the seasonal variation index indicate that,

- Summer Season with water temperature of 38°C ranks I, that recorded less water withdrawals in comparison with the rainy, moderately high loss of generation. Less WD- with an index of 137.67 and moderately high LG- with an index of 105.67.
- Rainy Season with water temperature of 32°C to 34 °C ranks II with more water withdrawals and high loss of generation. More WD-with an index of 152.37 and High LG- with an index of 153.75
- Winter Season with water temperature of 27°C to 32 °C ranks III with moderate water withdrawals and moderate loss of generation. Moderate WD- with an index of 65.3 and Moderate LG with an index of 79.33
- Post Monsoon season with water temperature of 31 °C ranks IV with moderate water withdrawals and moderate loss of generation. Moderate WD- with an index of 62.73 and Moderate LG with an index of 59.5

Narla Tata Rao Thermal Power Plant

The finding of one typical trial concerning to the cooling towers of NTPPS 6 × 210 MW is given below:

Observations

Unit load of the power station	1260 MW
Mains Frequency	23.3
Inlet cooling water Temperature °C	42.09 °C (Designed 41°C)
Outlet Cooling Tower water Temperature °C	34.37 °C (Designed 32.50 °C)
Air wet bulb Temperature near cell °C	24.58°C (28.2 °C)
Air dry bulb temperature near CT cell	34.60 °C (37.15 °C)
No: of CT Cells on line with water flow	12
Total measured cooling water flow m^3/hr	39637.50
Measured CT fan flow m^3/hr	589544

Experiential Analysis

- CT Flow/Cell, m^3/hr - 3303.12 (Rated 2750)
- CT Fan Flow, m^3/hr (Avg) - 589544
- L $(T_1-T_2) = G(h_2-h_1)$

$$\frac{L}{G} = \frac{h_2 - h_1}{T_1 - T_2}$$

$$= \frac{40.82 - 22.70}{42.09 - 34.37} = \frac{18.12}{7.72}$$

=2.3 (Rated 0.38)

- CT Range - 7.72 $^{\circ}$C (Rated 8.5 $^{\circ}$C)
- CT Approach - 5.17°C (Rated 4.5°C)
- % CT Effectiveness - (100* (Range / Range + Approach)

  = 100(7.72)/(7.72 + 5.17) = 59.89

- Rated % CT Effectiveness = (100* 8.5/ (8.5+ 4.5) = 65.38
- Cooling Duty handled /Cell in Kcal = 3303*7.72*103

  = 25499.16*10^3 (Rated 23375*10^3 Kcal/hr)

$$\text{Evaporation losses in m}^3\text{/hr} = \frac{\text{Circulation rate (m}^3\text{/hr)}^* \text{ Temperature in } ^{\circ}\text{C}}{675}$$

$$= \frac{3303.12 \times 7.72}{675} = 37.78$$

=37.78 m^3 /hr per cell

- Percentage Evaporation loss = 37.78 /3303 *100 = 1.14 percent
- Blow down requirement for site COC of 2.7 = Evaporation loss/COC -1

  = 37.78/2.7-1

  = 37.78/1.7 = 22.22 m^3/hr

- Make up water requirement /Cell in m^3 /hr = Evaporation loss + Blow Down loss

  = 37.78 + 22.22 = 60

Comments

- The actual percentage of cooling tower effectiveness is 58.89 percent whereas the designed percentage should be 65.38 percent.
- Algae growth found in cooling tower cells.
- The operating CT range is 7.72 $^{\circ}$C, whereas the design one was 8.5 ^{0} C.

Kothagudaem Thermal Power Stations (KTPS) - Stage V

The findings of KTPS Stage v for 2 × 250 MW is provided as follows

Observations/ Technical Parameters

Type of Cooling	Natural Draught cooling towers
Unit load of the station	2 × 250 = 500 MW
Design Capacity per tower	37,500 m^3 per hour
Type /quantity	PVC fills, counter flow /Hyperbolic
Hot water inlet cooling tower water temperature	46°C (Rated 42°C)
Out let cooling temperature	35 $^{\circ}$C (Rated 33°C)
Ambient wet bulb temperature	28 $^{\circ}$C (Rated 28 $^{\circ}$C)
Dry bulb Temperature	37°C (Rated 39 $^{\circ}$C)
Relative humidity	50 $^{\circ}$C
Diameter at sill level	99.10 m
Diameter at top	5907 m
Diameter at throat s	55.44 m
Tower height above sill	8910 m
Height up to bottom of fill above sill	6.30 m
Water trough top level above sill	9.15 m
Fill Material	PVC
Fill Depth	1.20
Fill Volume	7440 m^3
Water basin Capacity	23199 m^3

Experiential Analysis

CT Range - 11 $^{\circ}$C

CT Approach - 5 $^{\circ}$C

Humidity - 50 percent

Depression: Dry bulb- Wet bulb = 39-28 = 11 $^{\circ}$C

Percentage CT Effectiveness - (100* (Range/Range + Approach)

= 100(11 /11+5) = 100 (11/16) = 100 × 0.6875 = 68.75 percent

Percentage Rated CT Effectiveness = (100* (9/9 + 5) = 100 × 0.64285 = 64.28 percent

Evaporation losses = Condenser Capacity × % of evaporation, Evaporation losses - Rainy Season: 1.5 percent, Winter Season: 1 percent, Summer Season: 2.5 percent

Rainy = 32370 × 1.5% × 24 hrs = 11653.2 m^3 /hr, winter = 32370 × 1% × 24 hrs = 7768.8 m3 /hr, summer = 32370 × 2.5 % × 24 hrs= 19422 m3 /hr

Comments

- The actual percentage of cooling tower performance that stood at 68.75 is seemingly good in comparison with a rated percentage that stood at 64.28 percent.
- The evaporation losses are high during summer, medium during rainy and lower during winter.
- The depression varies with the level of 11 $^{\circ}$C.

Rayalaseema Thermal Power Station (RTPP) - Stage II

The findings of RTPP Stage II cooling towers for 2 × 210 MW is given as follows

Observations/ Technical Parameters

Type of Cooling	Natural tower Draught Hyperbolic
Unit Load of the Station	420 MW
Design capacity per tower	37500 m^3/hr
Type of air flow	Counter Flow
Inlet cooling tower water temperature	45 $^{\circ}$C (Designed 43 $^{\circ}$C)
Outlet Cooling tower water temperature	35 $^{\circ}$C (Designed 33 $^{\circ}$C)
Design Approach	5.8 $^{\circ}$C
Cooling range	10 $^{\circ}$C
Ambient Wet Bulb Temperature	25 $^{\circ}$C (Designed 27.2 $^{\circ}$C)

Dry Bulb Temperature	36 $^{\circ}$C
Relative Humidity	40 percent
Diameter at foundation Center line	108.054 mtrs
Diameter at sill level center line	105.500 mtrs
Diameter at throat level center line	61.200 mtrs
Diameter at top of cooling tower Center line	63.200 mtrs
Height of the tower	p + 126.75 mtrs

Experiential Analysis

CT Range - 10°C

CT Approach - 10°C

Humidity - 42 percent

Depression - Dry bulb temperature – Wet Bulb Temperature = 11°C

% CT Effectiveness = (100 * (Range /Range + Approach)

= 100 (10/10+10) = 100 (10/20) = 100 × 0.50 = 50 percent

% Rated CT Effectiveness = 100 (10/10 + 8) = 100 × 0.56 = 56 percent

Evaporation losses = Condenser Capacity × % of evaporation, Rainy Season – 1.5%, Winter Season- 1%, Summer Season- 2%, Rainy Season= 28900 × 0.015 × 24 hrs = 10404 m^3/hr, Winter Season = 28900 × 0.01 × 24 hrs = 6936 m^3/hr, Summer Season = 28900 × 0.02 × 24 hrs = 13872 m^3/hr

Comments

- The actual percentage of CT effectiveness is 50 percent, whereas the designed percentage should be 56 percent.
- The evaporation losses are high during summer season, medium during rainy season and lower during winter season.
- The depression varies to the level of 11^0 C.

DISCUSSION AND CONCLUSIONS

The new norms can have a remarkable reduction in freshwater withdrawal by thermal power plants—cumulative freshwater withdrawal could decrease by 80 percent from around 22 BCM in 2011-12 to around 4.5 BCM in 2016-17. The norms will require all freshwater based once-through-cooling (OTC) system plants to install water-efficient cooling towers that consume up to four cubic metres per watt hour (m3/MWh). Furthermore, existing cooling-tower-based plants will need to restrict water consumption to 3.5 m3/MWh and plants that will be set up after January 2017 have to achieve 2.5 m3/MWh. Renewable energy, collectively provides only about 7 percent of the world’s energy needs. This means those fossil fuels, along with nuclear energy — a non-renewable energy source — are supplying 93% of the world’s energy resources. Renewable energy is energy that is derived from natural processes (e.g. sunlight and wind). Solar, wind,

geothermal, hydropower, bioenergy and ocean power are sources of renewable energy. “It is commonly assumed that greenhouse gas and energy problems can be solved by switching from fossil fuel sources of energy to renewable. However, little attention has been given to exploring the limits of renewable energy.

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